Document 8

CONSIDERATIONS REGARDING THE USE OF SATELLITE IMAGERY FOR WEST COAST SARDINE SURVEYS

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I. Introduction and Background

Since the West Coast Aerial Sardine Survey began two years ago it has become apparent that photographs taken by satellites might provide an additional and efficient source of valuable data. The present method of determining the surface areas of sardine schools is done with digital cameras taking pictures from small airplanes at 4,000 feet. This is an acceptable method but it does have limitations.

The speed of a single engine aircraft makes covering a large portion of the ocean in a short amount of time difficult. In order to have a synoptic collection of data, say from the Pacific Northwest to Southern California, an airplane flying survey transects may take several days or, if hampered by weather, even weeks. By comparison, a satellite can travel the entire West Coast in a matter of minutes.

The amount of ocean surface area being photographed with airplanes can be greatly increased by adding satellite imagery. It may even be possible to cover the entire West Coast completely – thus eliminating the need for statistical extrapolation.

The Northwest Sardine Survey contacted GeoEye, a satellite data brokerage company that provides images for public and private uses. After viewing samples of their images it was evident that sardines could be photographed from a satellite. A test was set up with the help of Spatial Imaging Solutions to photograph an area of known sardine abundance on the southern Washington coast. The satellite's computer was programmed to capture a series of images with: 1) a weather parameter of 90%, 2) clear skies, and 3) low water vapor concentration. On August 23, 2009, the IKONOS satellite took a set of images just north of the mouth of the Columbia River, near Willapa Bay, from an elevation of 425 miles (Figure 1). A small section of this sampled area is enlarged and shown in Figure 2. Using image processing techniques similar to those employed by the West Coast Aerial Sardine Survey, it is straightforward to identify, enhance, and quantify the surface area of sardine schools on images of this type.

Utility of Satellite Imagery for the Assessment of Pacific Sardine

With respect to providing inputs to the Pacific sardine stock assessment, the use of satellite imagery (SI) affords an alternative to the aerial sardine survey as a means to estimate absolute abundance. Effectively, the same analytical methodology is employed to estimate biomass; the difference, however, is that SI can be used in place of aerial photography (of sampled transects) to measure total sardine surface area.

In lieu of transect sampling; large swaths of the ocean surface can be covered with one pass of the satellite in a matter of minutes. With this increased synopticity, it is conceivable that SI could provide a virtual *census* of sardine school surface area, without the need for statistical extrapolation. This would replace the aerial survey *estimate* of surface area from transect sampling, with its corresponding uncertainty due to sampling error. Reducing uncertainty in the estimate of sardine surface area leads to a reduction in the uncertainty of the estimate of absolute abundance, and hence a lower CV than can be obtained from the airplane transect approach. Clearly, point set sampling will still be required to relate surface area to biomass, and biological sampling of the schools is still needed to establish a selectivity curve for the stock assessment model.

Advantages of Using Satellite Imagery to Measure Sardine Schools

Advantages of the SI approach to estimate absolute abundance include: 1) more efficient use of survey dollars (e.g. less impact from bad weather conditions, and greater area covered per dollar), 2) less potential for equipment bias (e.g. one measurement tool instead of multiple airplanes and camera systems), and 3) essentially "instantaneous" sampling (meets random sampling assumptions better than airplane sampling over a period of weeks, and substantially reduces the possibility of "double counting" sardine schools).

In addition to estimating absolute abundance, the SI approach can provide new information on the temporal and spatial distribution of sardine, which is useful for: 1) inferring migration patterns, and 2) providing pre-stratification guidance to facilitate the design of other surveys (e.g. acoustic or aerial surveys) to reduce the variance of survey estimates.

Challenges and Limitations of Using Satellite Imagery to Measure Sardine Schools

Many of the challenges and limitations that apply to the aerial survey methodology apply to the SI approach as well. Sources of uncertainty identified for the West Coast Aerial Sardine Survey by the May, 2009 STAR panel are presented in Appendix I.

For Stage 1 sampling (estimation of sardine surface area), three categories of uncertainty sources are: 1) species misidentification, 2) school detection, and 3) school area determination. A disadvantage specific to the SI approach is that it forgoes transect sampling by experienced spotter pilots, who provide at-sea observations to assist with species identification. Conversely, some of the concerns with aerial photography are reduced with SI. For example, the impact of imagery "edge effects" is virtually nil, and the role of prohibitive weather conditions is reduced considerably with the SI approach.

Essentially all of the sources of uncertainty summarized in Appendix I for Stage 2 sampling (estimation of biomass per unit area) also apply to the SI approach, because the same means is used to derive biomass per unit area (point set sampling). However, the SI approach may afford some advantages by better linking of the Stage 1 and Stage 2 sampling efforts. For example, examination of the satellite images (Stage 1) prior to point set sampling (Stage 2) may facilitate the process of obtaining the target size and spatial distribution of point sets required by the study design. This linkage could help to ensure the representativeness of the point set sampling.

II. Survey Design Considerations

Consideration of the SI approach is in its early stages, and a detailed survey design has not yet been developed. Some aspects of a potential survey design using the SI approach are discussed below.

Spatial and Temporal Coverage
One clear advantage of the SI approach is the speed at which this technique covers a large area of ocean surface. Spatial coverage could thus extend synoptically from the US-Canada border to the US-Mexico border. Species/stock identification issues could influence the reliability of the information obtained from near the southern extent of coverage; this factor will clearly have a role in specifying the spatial coverage for the survey. Temporally, it is desirable to do test sampling in more than one season to define the optimal survey timing for estimation of total biomass. A practical consideration is that purse seine fishing vessels, and harvestable quota, must be available for point set sampling at the same time the SI imagery is collected.

Statistical Sampling Protocols
The aerial survey uses a systematic random sampling methodology in which the sample unit is the transect. The SI data come in large swaths and could be randomly sampled, or alternatively analyzed in their entirety for a virtual "census" of sardine school area. An evaluation of the cost/benefit trade-offs will need to be conducted to decide on the best approach.

Data Collection
The SI data needed for the survey can be purchased from brokers who specialize in providing this service. Trained photo analysts (such as the team put together for the West Coast Aerial Sardine Survey) can be employed to process the imagery. Processing involves the use of software to enhance the images to reveal the presence of sardine schools, and using software measurement tools to collect the school surface area data. Alternatively, pattern recognition software could eventually help to automate this process (Lakshman and Skourikhine 2006).

Data Analysis
With data in hand from Stage 1 (sardine surface area) and Stage 2 (biomass per unit area) sampling, the methodology for obtaining an estimate of total biomass is effectively the same as that currently employed by the West Coast Sardine Survey (Jagielo et. al. 2009). Likewise, bootstrap methods can be employed to estimate the variance of the abundance estimator.

III. Cooperative Survey Workshop Discussion Points

Linkage to Other Methods
The SI approach is clearly linked with the aerial survey method. The use of SI could entirely supplant, or alternatively it could complement, the use of airplane transect photography to estimate sardine school surface area.

Other survey methods, such as acoustics, could potentially benefit by using SI data showing sardine school distribution. This information could aid in survey pre-stratification for the purpose of improving acoustic survey efficiency and variance reduction. Also, it is clear that acoustics can measure sardine biomass below the ocean surface that can't be seen via SI. A survey combining both techniques could potentially benefit from: 1) the increased synopticity of SI, and 2) the ability of acoustics to quantify the proportion of schools not seen by SI.

Opportunities for Collaboration
NOAA Fisheries should consider being involved with satellite imaging for future sardine assessments. The analysis of SI is a reliable and cost efficient method to measure real world conditions. When compared to the cost of satellite imaging, other techniques (e.g. trawling and DEPM) are much more expensive and provide uncertain results.

Industry will continue to develop and test satellite imagery if NOAA doesn't take the lead. However, it is preferred that this endeavor be conducted by experienced SI experts. Fisheries management and industry will be well served by NOAA's participation in this project.

IV. Bibliography

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Spatial Imaging Solutions. Personal Communication; Jeff Campbell, Bend OR .
Phone: 541-388-8868

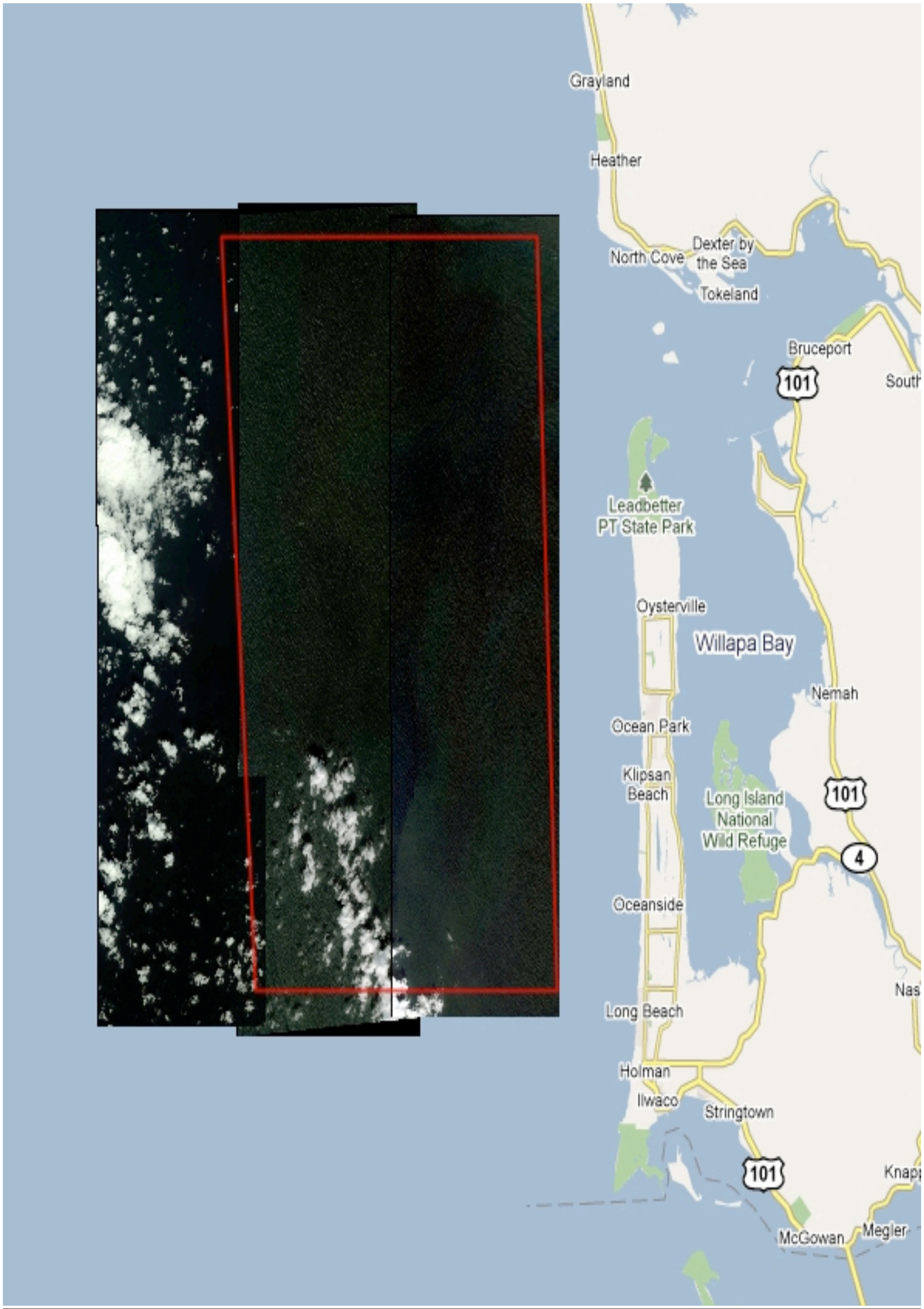

Figure 1. Area off the southern coast of Washington photographed by the IKONOS satellite on August 23, 2009.

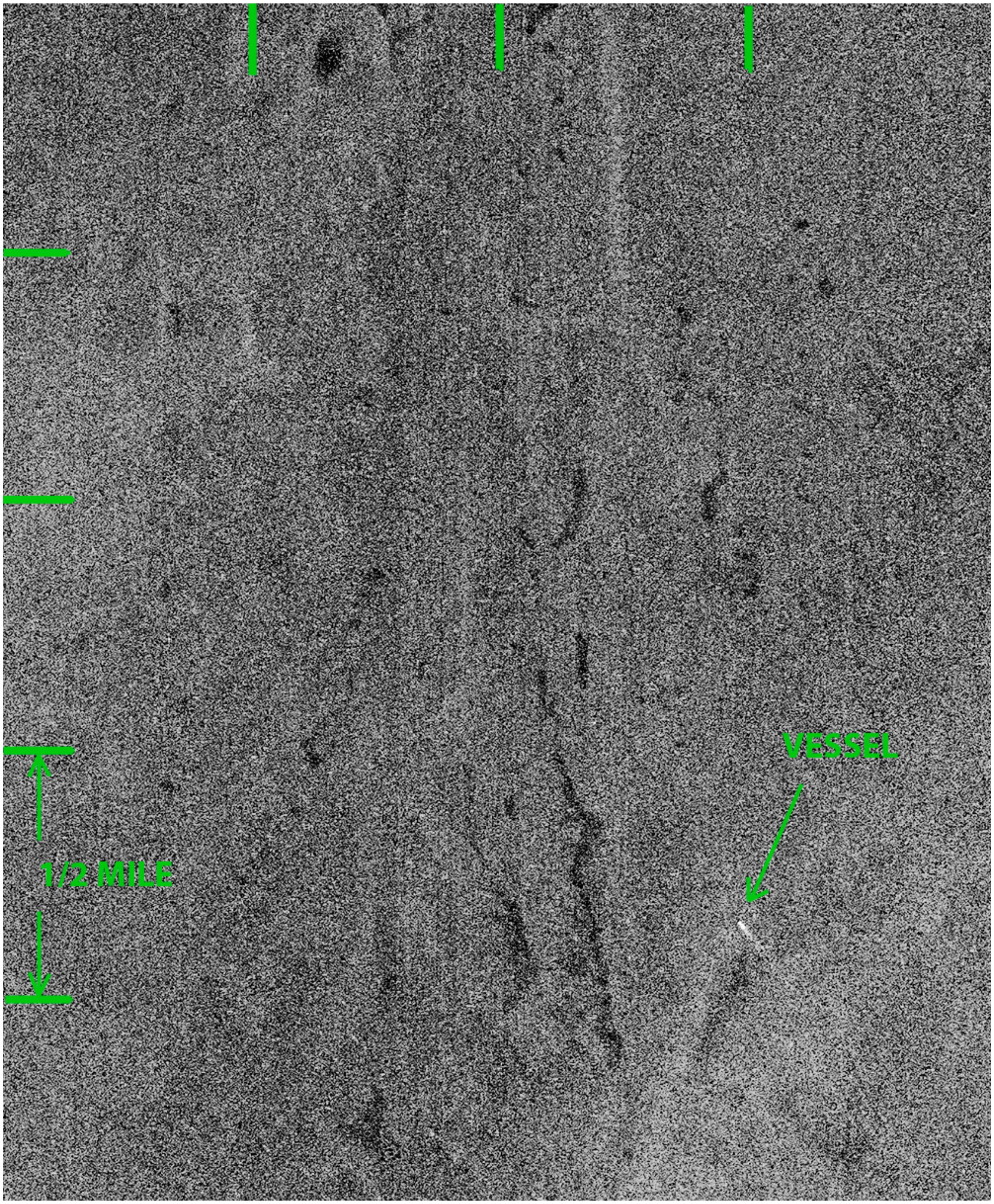

Figure 2. Satellite imagery showing a small portion (approximately 5 sq. mi.) of the area photographed by the satellite on August 23, 2009.

Appendix I: Sources of uncertainty in proposed aerial sardine survey identified by the May, 2009 STAR Panel

Stage 1 – Estimation of sardine school area

Source of Uncertainty or Bias	Direction & Size	Ways of Addressing the issue
Category: Species misidentification		
Type 1: Sardine misidentified as other spp./features	Underestimate	Directed sets, jigging, include low overflight
Type 2a: Other spp. misidentified as sardines	Overestimate	Directed sets, jigging
Type 2b: Other features misidentified as sardine	Overestimate	Avoid cloudy conditions ??
Density dependent misidentification (a nonlinearity)	Hyperstability?	Long-term comparisons
Variability among pilots		
Category: School detection (note: timing needed for assessment schedule is not optimal for survey conditions)		
Schools too deep	Underestimate	Quantify water clarity (e.g. secchi depth), Echo sounder evidence
Schools lost in glare	Underestimate	Time of day, compare adjacent frames
Schools too diffuse (hypothetical)	Unknown	Relate to behavioural patterns?
Marginal cloud cover, reduced visibility	Underestimate	Determine range of acceptable conditions
Sea state	Underestimate	Determine range of acceptable conditions
Technician variability–image enhancement	Unknown	Double-blind re-analyses
Weather is consistently prohibitive	Unknown	Use better season and delay input one year
Category: School area determination		
Calibration of scale (photogrammetry)	Overestimate (maybe neutral)	Continue calibration
Calibrate distortion at edge of frame	Unknown	Continue calibration
Precision and repeatability	Unknown	Repeat photos of same school over time; Compare morning and afternoon views
Schools extending outside visual frame	Depends on B/A relationship	Problem mainly if nonlinearity exists
Diffuse school boundary	Overestimate?	Disturb with vessel and compare area?
Complex shape or diffuse	Overestimate?	Repeat photos of same school over time; Disturb with vessel and compare
Technician variability–image enhancement	Unknown	Blind" reanalyses of photos, within and among technicians.

Stage 2 – Estimation of biomass per unit area

Source of Uncertainty or Bias	Direction & Size	Ways of Addressing the issue
Comparability to images in Stage 1	Unknown	Choose conditions and school types similar to aerial survey. Use similar altitude.
Pro-sardine target selection	Overestimate	Select schools only on size criterion
Nonlinear biomass/area relationship	Unknown	Increase sample size, contrast
Statistical imprecision	Unknown	Increase sample size
Regional differences	Unknown	Compare northern and southern cases
Behavioural patterns		
Feeding, spawning, transiting	Unknown	Stratification
Mixed species	Unknown	
Response to fishing vessel	Overestimate	Get photo before vessel approaches
Oceanographic conditions (e.g., El Nino)	Overestimate (contraction)	Caution in among-year data sharing
Distance offshore	Unknown	
Present but undetectable–directed sets impossible	Underestimate	Conduct blind sets (e.g., Pearcy's work)
Variable relationship depending on school thickness	Unknown	Voluntary logbooks at time of survey to compare school thicknesses among years
Density-dependent mixed schooling	Unknown	Long-term fishery catch compositions

Source of Uncertainty or Bias	Direction & Size	Ways of Addressing the issue
Abundance estimation		
Pre-integrate area–works if there is linearity	Unknown	Depends on Stage 2 results; Edge effect is neutral if linear
Integrate biomass over schools–works best if nonlinear	N/A	Need to deal with edge effects
Other		
Survey stratification (transect density depends on school density)	N/A	Possible with further experience, but not currently proposed
Survey does not cover whole area	Underestimate	Maybe extend transects offshore; Go into Canada, Mexico